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New Bovid (Artiodactyla) Fossils from the Siwaliks of Pakistan: Reviving a Lost World

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This study investigates newly discovered fossil specimens of bovids (Artiodactyla) from the Siwalik Group of Pakistan, with the aim of enhancing the understanding of South Asia's paleoecology and evolutionary history. It provides new insights into the taxonomy and diversity of Siwalik bovids, addressing existing gaps in the fossil record and contributing to a more comprehensive understanding of their evolutionary relationships. Seven new dental elements of bovids, including both upper and lower dentitions, were recovered from the villages of Dhok Pathan and Hasnot in the Potwar foreland basin of the Himalayas in Pakistan. These fossils excavated from the Dhok Pathan Formation within the upper Siwaliks Group, deposited in environments ranging from river channels to floodplains, providing chronological and environmental contexts for the assemblages. Based on comparative morphology and precise measurements, the mandible was identified as belonging to *Selenoportax vexillarius*, while the molars and premolars were attributed to *Pachyportax latidens*, *Pachyportax nagrii* and *Kobus porrecticornis*. Comparative analysis with fossils from other regions ensures the accuracy and relevance of the findings, contributing to a refined understanding of the evolutionary history and biogeographic patterns of these species. This study documents the paleoecology of the region, indicating a grassland and woodland biome supported by the tectonic setting of the Himalayas orogeny, which collectively created a favorable scenario for bovid diversity. The examined fauna suggests a vast, open landscape with intermittent dry and flood seasons, creating a mosaic of ecotonal habitats with numerous niches. This research enhances our understanding of Artiodactyla's past biodiversity and environmental challenges, highlighting the significance of the Siwalik Group for studying their evolutionary history and emphasizing the need for ongoing exploration and analysis of its fossil record.

Keywords: Palaeontology; Taxonomy; *Selenoportax; Pachyportax; Kobus*; Siwaliks.

Introduction

The Bovidae family diverged within the Ruminantia order during the Early Miocene, approximately 20 Ma, marked by a global cooling trend, which coincided with the evolution of grasses adapted to a cooler and drier climate [1]. The middle Miocene marked the expansion of bovids into both China and the Indian subcontinent, subsequently, in the late Miocene (10 Ma), bovids experienced a rapid diversification, giving rise to 70 new genera [2]. Faunal interchanges and turnover in the Siwaliks during the Miocene were classified into three distinct episodes: one from 22 to 18 Ma, another between 15 and 13 Ma, and a third around 9.5 Ma [3-5]. This classification was subsequently refined, and based on a more precise time resolution, it identified periods of heightened Late Miocene turnovers at 10.3, 7.8, and 7.3–7.0 Ma [6].

Meanwhile, from 20 to 10 Ma, the Indian Plate, already in collision with the Eurasian Plate, experienced an approximate 40% drop in convergence rate to less than 5 cm/yr. [7, 8] as compare to its previous rate of >11 cm/ yr. [9, 10]. During this time Himalayas were in the process of uplift, erosion, transportation, and deposition [11, 12], processes that continue to shape the region. The Siwaliks Rock Group (hereafter Siwaliks), extending along the Himalayan foothills from Pakistan in the west to Nepal in the east, provide an uninterrupted record of fossil mammals [13]. It exhibits a grain size transitions from finer to coarser upward sequence, and an increased sedimentation rate, reflecting a gradual rise in the erosion rate of the Himalayas [14].

Considering the close linkage between Bovids diversity and plate tectonics is intriguing. The tectonic influence on climate, being a pivotal element, possesses the capability to alter surface albedo and substantially perturb atmospheric pressure patterns. For Instance, the Himalayas, serve as a barrier against the migration of the Siberian high and westerlies, and also controls the Asian monsoon, driven by the seasonal shift of atmospheric pressure over the region and establishing it as best known atmospheric-circulation system [14]. Although the connection between orogenic process, erosion rate and climate are complex, however, robust weathering (physical and chemical) of an active orogenic belt acts to remove CO_2 from the atmosphere [15], ultimately facilitating global cooling [16]. Such processes may offer an explanation for intensified monsoons in Late Miocene, resulting in the landscape dominated by grasslands and forests, subsequently leading to the diversification of Bovids in this region.

During the Late Miocene, Bovids expanded their territorial range from their evolutionary origins, evidenced by widespread fossils in the Siwaliks, particularly within the Dhok Pathan Formation [17-20]. Magnetic polarity and stratigraphic dating have effectively constrained the age of the Dhok Pathan Formation to a span between approximately 10.1 million years ago and around 3.5 million years ago [20]. The Siwaliks' fossil deposits span an impressive 18 million years of artiodactyls, prominently featuring Bovids, yet our understanding of their systematics and evolution in this area remains outdated and limited [21, 22]. Bovids, occupy a range of habitats, and several bovid species have been discovered in the Neogene deposits of the Siwaliks [6].

This study focuses on two specific sections within the Dhok Pathan Formation: Dhok Pathan Village in the central region and Hasnot Village in the southern region of the Potwar basin (Figures 1 and 2). These historically significant locations, renowned for their Late Miocene vertebrate fauna, exhibit a notably higher prevalence of bovid fossils compared to other areas. The current study introduces new bovid specimens from the Dhok Pathan Formation, providing valuable insights into their presence within this formation.

Objectives and Novelty Statements

The research aims to provide a comprehensive overview of numerous species of Artiodactyla found in the Middle Subgroup of Siwalik, Pakistan, between the Late Miocene and the Early Pliocene by measuring and recording new fossil samples using predefined patterns like, Baker et al., [23]; and Akbar et al., [24]. It documents the diversity of Artiodactyla during the Late Miocene, examining various aspects of their palaeontology, including taxonomy, biostratigraphy, and paleoecology. This study introduces new fossil measurements, offers detailed taxonomic insights into a high diversity of species, and establishes a refined biostratigraphic framework for the region. It uncovers new paleoecological patterns, shedding light on the ecological roles and interactions of Artiodactyla, and provides novel reconstructions of the paleoenvironmental conditions in the Siwalik region during the Late Miocene. By employing various techniques, strategies, and perspectives to address a complex issue or achieve a comprehensive outcome, this research enhances the understanding of the historical climate and habitat changes, contributing significant taxonomic, ecological, biostratigraphic, and palaeoenvironmental data to the field of paleontology.

Geological Setting Study Area

Pakistan occupies a geographically significant position, where the Indian, Eurasian, and Arabian Plates converge, creating a unique tectonic framework [25]. This geological narrative began with the breakup of Gondwanaland [26, 27], followed by the formation and breakup of Pangea [28], leading to the opening and subsequent closure of the Neo-Tethys Ocean [29, 30]. These processes eventually led to the Indo-Eurasian collision [31] and Arabian-Eurasian subduction [32], resulting in the formation of several typical geological features. The Himalayas among them, stand out as the Earth's highest and youngest mountain range [27, 33], formed on the leading edge of the Indian Plate as a result of its ongoing northward collision with the Eurasian Plate [12, 34]. In the western Himalayas of northern Pakistan (present day) [11], these orogenic activities over the past 40 million years have profoundly shaped the development of regional sedimentary basins such as the Kohat-Potwar Basin [27, 35] (Figure 1). During the Early Miocene, it functioned as the primary deposition site for Himalayan syn-orogenic sediments (molasse), which have since been uplifted and deformed, retaining the traces of the Himalayan Orogeny [36-38]. In the Middle Miocene, the northward movement of the Indian Plate caused crustal shortening, giving rise to the Himalayas and the subsidence of the foreland basin [39, 40].

The Indo-Gangetic River systems deposited thick sediment layers in large floodplains, under a warm and humid climate, supported by evidence from abundant paleosol deposits and variety of fossilized rainforest flora [41, 42]. Significant tectonic activity around 12 Ma along the Main Boundary Thrust (MBT) [43], resulted in a shift to a meandering river pattern [44], and substantial increases in sediment-accumulation rates, sandstone-siltstone ratios, and sandstone body thickness were recorded [45, 46]. The transition from a mudstone-dominated to a sandstone-dominated succession in the Siwaliks is time-transgressive and took place around ~11 million years ago in the Potwar Basin. Approximately 10 Ma in the late Miocene, there was a transition in the fluvial landscape, marked by the shift from minor to major sandstone bodies, indicating an expansion in channel size and overall discharge, implying deposition within a significant braided river system [47]. Early Pliocene tectonic activity deposited thick conglomerates with sandstone and mudstone lenses [48]. Subsequent MBT reactivation and river reorganization around 5 million years ago led to the formation of lateral coalescing mega-fans with varied sediment characteristics [47, 49]. Early Pleistocene tectonic activity, driven by MBT and Main Central Thrust in the Himalayas [50], altered sedimentation patterns and river systems [47], impacting large mammal habitats [13]. Siwalik paleosols reflect changing climates [51], with stable isotope studies indicating monsoon intensification at different periods i.e., 11, 6 and 3 Ma [52] .

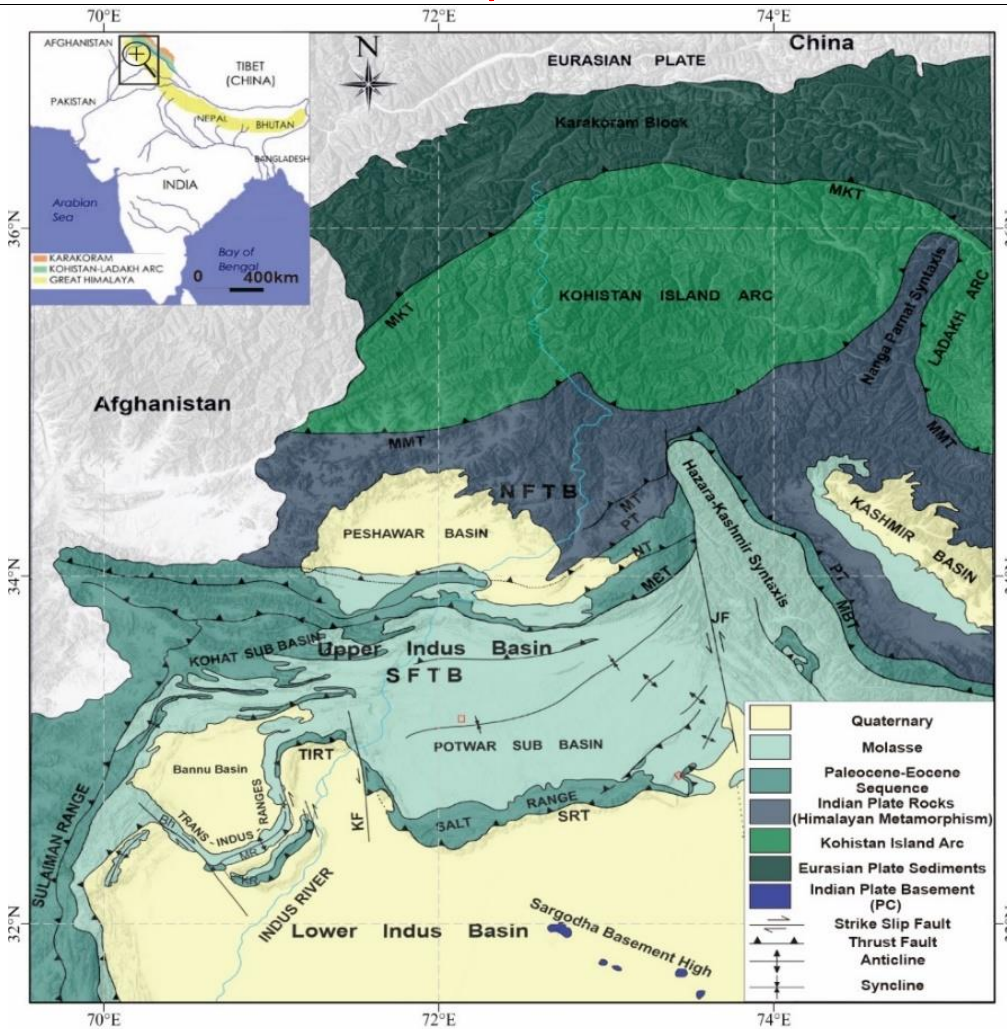

Figure 1: Generalized geological map of the NW Himalayas on the topography background, modified after Kazmi and Rana, [53]. Red rectangles show the location of study area. MKT. main Karakorum thrust; MMT. main mantle thrust; MBT. main boundary thrust; NFTB. northern fold and thrust belt; SFTB. southern fold and thrust belt; MT. Mansehra thrust; PT. Panjal thrust; NT. Nathiagali thrust; HKS. Hazara Kashmir syntaxis; JF. Jhelum fault; KF. Kalabagh fault; SRT. Salt range thrust; TIRT. Trans Indus range thrust; MR. Marwat range; KR. Khissor range.

These molasse are extensively deposited in the Kohat-Potwar plateaus in Pakistan, mainly striking in an east-west direction, with the Salt Range Thrust (SRT) and Trans-Indus Range Thrust forming their southern boundary and the MBT delineating the northern boundary (Figure 2). These mainly consist of two main groups i) Rawalpindi Group of Early-Middle Miocene and ii) Siwaliks of Middle-Late Miocene [54, 55]. Based on magnetic time scales, the Potwar plateau exhibited an estimated average sedimentation rate of 0.8 meters per 1000 years, with fluvial cycles occurring approximately every 56,000 years, and the major sandstone units show minimal time transgressions in an east-west direction [56].

The Siwaliks are further subdivided into the Chinji, Nagri, Dhok Pathan, and Soan formations, following their depositional sequence, including a wide range of vertebrates of Miocene. Particularly, the Late-Miocene Dhok Pathan Formation is rich in Mammal faunas, which is similar to those found in the Turolian-Land 'Age,' as defined in European, North-African and west-Asian regions [57]. It is widely exposed in the Potwar Plateau typically characterized by repetitive cycles of grey sandstone and variegated clay beds, often interspersed with conglomerate lenses [55].

Our field study was mainly targeted on two outcropped sections of Dhok Pathan Formation i.e., 1) Dhok Pathan village and 2) Hasnot village (Figure 2). Section-1 is the type locality of Dhok Pathan Formation lies in district Chakwal, while the section-2 located in the Jhelum District of Pakistan. Geologically, setion-1 lies in the core of major Soan Syncline, however the section-2 in the hanging wall of the SRT, both represents the typical geological sections, renowned for diverse collection of Middle Siwalik faunas.

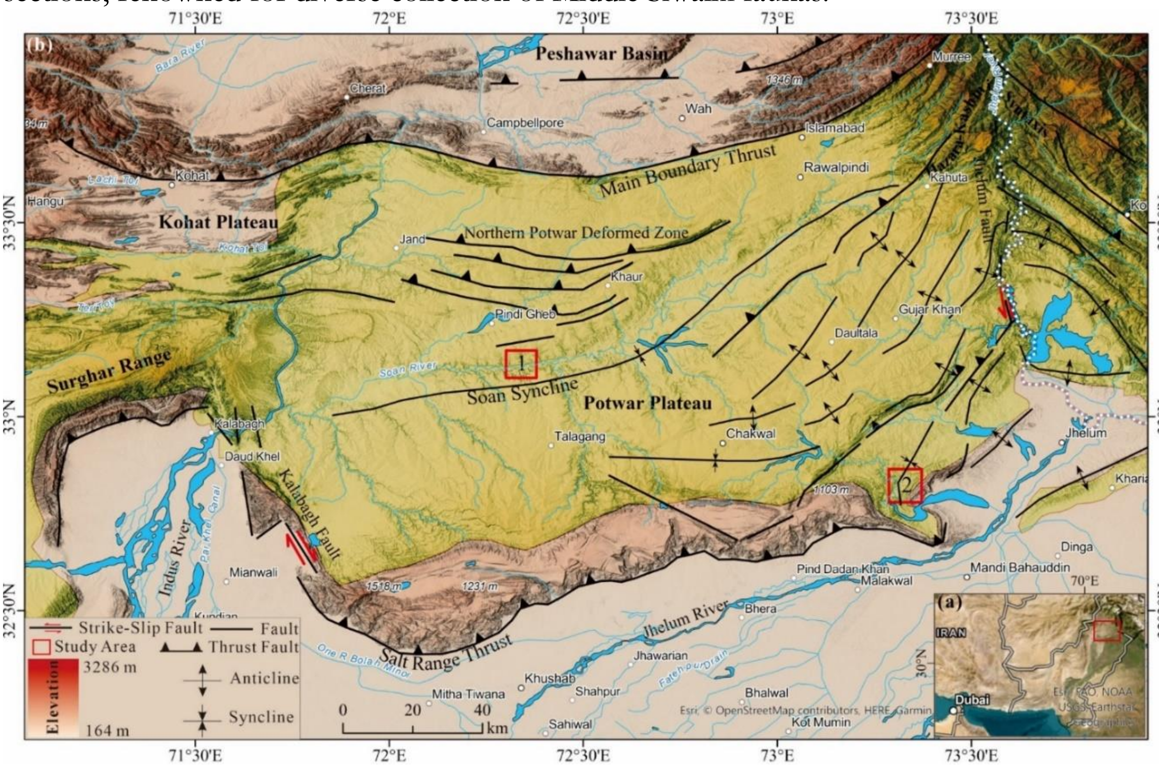

Figure 2: (a) Landsat image showing the location of (b) a generalized structural map of Kohat-Potwar plateaus and surrounding areas on a Digital Elevation Model background. Structural elements derived from tectonic map of Pakistan [53]. Greenish color represents the molasse deposits. The red rectangle indicates the location of study area with 1 (Dhok Pathan Village) and 2 (Hasnot Village).

Material and Method:

Data collection:

The outcrops in Section-1 (Dhok Pathan) and Section-2 (Hasnot) (Figure 2) were extensively surveyed, and samples were gathered during different field visits from October to December in 2020. Surface sampling was the primary method of collection, complemented by careful excavation using geological hammers, chisels, needles, knives, brushes, and hand lances. A significant portion of the material was sourced from Section-1 (Six samples), while a few specimens were collected from Section-2 (1 sample), (Table 1, and Figure 3). Specific section locations as illustrated in the Figures 1, stated in parenthesis with the new material.

In the field, specimens were carefully wrapped for transport, underwent thorough cleaning in the laboratory. Subsequently, morphological and taxonomic analyses were conducted and presently housed in the in Okara University's Department of Biology, Okara, Pakistan, as master's research project was conducted at Okara University, utilizing their advanced facilities and laboratories. The Department of Biology provided essential infrastructure, including molecular biology labs and biodiversity repositories, which were crucial for the successful completion of my study.

Data Analysis:

Precise measurements of the studied specimens were taken using a Vernier caliper, with all measurements recorded in millimeters (mm). The sample's catalogue number is structured to indicate the year of collection (numerator) and the serial number (denominator) for that year (e.g., UOPC 20211/01, UOPC is an institutional abbreviation- University of Okara Paleontological Collection). Tooth terminology followed by [58-60] identifies specific dental features, such as the entostyle on the lingual side of the upper molar and ectostylid on the labial side of the lower molar [18]. Measurements were taken occlusally at maximum level and expressed in millimetres. Uppercase letter with number represents the upper dentition (e.g., M) and lowercase letter with number indicates the lower dentition (e.g., m). Comparative analysis involved referencing fossils housed in institutions including the Geological Survey of Pakistan (GSP), the Government College University Faisalabad, Pakistan (PC-GCUF), and the Dr. Abu Bakr Fossil Display and Research Center, Dep (PUPC) [61] involved selecting relevant specimens and taking detailed morphometric measurements, supported by high-resolution photographs. Published data from these collections were reviewed and, where possible, direct physical comparisons or the use of casts and 3D scans were made. The visual representation of the methodology is shown in Figure 3, which illustrates the step-by-step methodology of research.

Taxonomic Description:

The systematic order lists species with comprehensive descriptions, comparisons, and discussions. A comprehensive and detailed morphologic investigation yielded taxonomic distinguishing evidence for seven animal species [62]. In systematic request, differentiated mammalian species are recorded with data on type species, nonexclusive determination, holotype, explicit discovery, stratigraphic range, geographic dispersion, new material, portrayal, correlation, and discussion [63, 64].

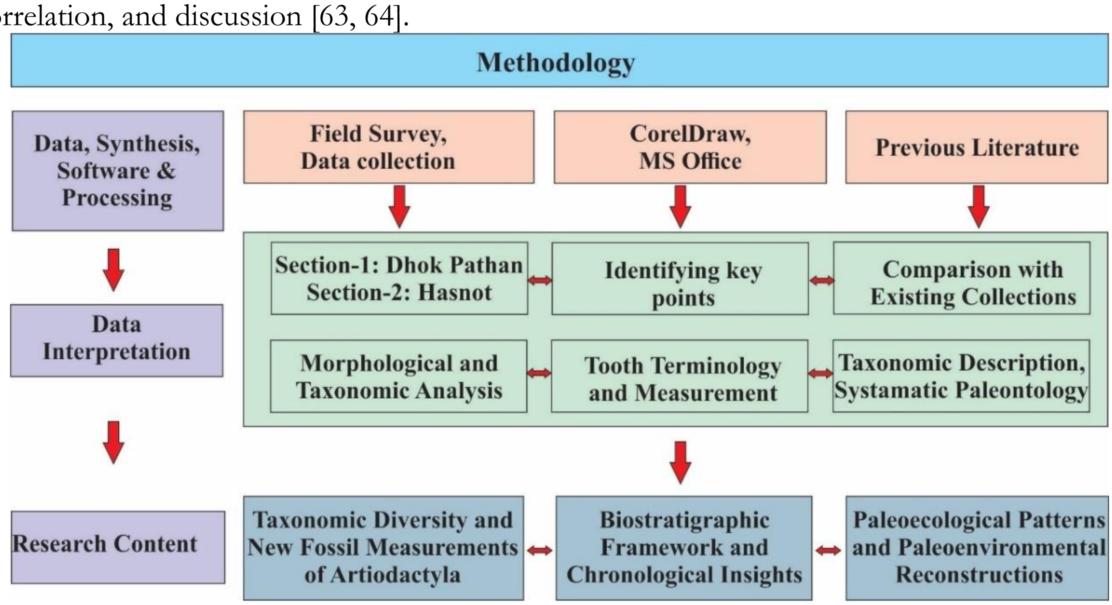

Figure 3: Visual Representation of Methodology Flow Chart.

Table 1: Material is collected from Dhok Pathan Formation of the Siwaliks Pakistan for this study.

Inventory Number	Description	Section
UOPC 2021/01	Right mandibular fragment with partial m3	1
UOPC 2021/02	An isolated right M2	2
UOPC 2021/03	An isolated partially broken right m3	1
UOPC 2021/04	An isolated right p4	1

UOPC 2021/05	An isolated highly damaged upper pre molar	1
UOPC 2021/06	An isolated left m2	1
UOPC 2021/07	An isolated left deciduous p4	1

Results:

Systematic Paleontology:

Family Bovidae Gray, 1821

Subfamily: Bovinae Gill, 1872

Tribe: Boselaphini Simpson, 1945

Class: Mammalia Linnaeus, 1758

Order: Cetartiodactyla Montgelard, Catzeflis and Douzery, 1997

Genus: Selenoportax Pilgrim, 1937

Species type: *Selenoportax vexillarius* Pilgrim, 1937

New Material: UOPC 2021/01, m3 (Section-1)

Description and Comparison:

The right M^3 (UOPC 2021/01) specimen from the Dhok Pathan Formation in the Siwaliks, Pakistan, is well-preserved, as depicted in Figure 11 (1a, 1b, 1c). Anterior lingual valley is more prominent then posterior and medial lingual valley. The specimen exhibits strong and divergent stylids, with the entostylid being particularly prominent. On the posterior side, hypoconulid is also present with m3. Prominent ribs and ectostylids are observed, and in the labial view (Figure 11, 1c), a narrow, pointed entoconid and protoconid are clearly visible. Hypoconid is present in slightly damaged condition. The morphology of the specimen resembles with *Selenoportax vexillarius* and differs from *pachyportax* due to their size and shape. Therefore, the specimen refers to *Selenoportax vexillarius* (Figure 11 and 4 (a, b, and c).

Table 2: The comparative measurements (mm) of the Selenoportax vexillarius. *The studied specimens. Referred data is taken from Khan et al., [19].

Taxa	Inventory Number	Nature/Position	Length	Width	W/L
Selenoportax vexillarius	UOPC 21/01*	m3	23mm	12mm	0.52
	PUPC 15/154	rP4	18.3mm	19.92mm	1.09
	PUPC 14/71	lM2	24.25mm	20.65mm	0.85
	PUPC 13/243	lM2	27.64mm	27.27mm	0.99
	PUPC 15/296	rdp4	26.15mm	10.68mm	0.41
	PUPC 14/122	lp4	20.46mm	12.08mm	0.59
	PUPC 14/113	lp4	21.57mm	11.06mm	0.51

Figure 4: (a) *Selenoportax vexillarius*: UOPC 2021/01 Occlusal view right mandibular fragment with partial m^3.

Figure 4: (b) *Selenoportax vexillarius*: 2021/01 lingual view right mandibular fragment with partial m^3.

Figure 4: (c) *Selenoportax vexillarius*: 2021/01 Labial view right mandibular fragment with partial m^3.

Genus: Pachyportax Pilgrim, 1937:
Species type: *Pachyportax nagrii* Pilgrim, 1937
New Material: UOPC 2021/02, M2 (Section-2)
Description and Comparison:

The specimen exhibits prominent ribs on the lingual view of upper molar teeth. The small molar shows upper dentition, consisting of divergent styles and mesostyle is less prominent. Constricted lobes are present on the lingual side and the open fossettes are present in the upper dentition. The protocone is V shaped and lower than hypocone. Postprotocrista is evident alongwith the projection of entostyle begins. The overall morphology of the sample attributes towards *Pachyportax nagrii* due to smaller size as compared to *Pachyportax latidens*. So, it is referred as *P*. cf. *nagrii* (Figure 11 and 5 (a, b, and c).

Table 3: The comparative measurements of Pachyportax nagrii. *The studied specimen. Referred data is taken from Waseem et al., [65].

Taxa	Inventory Number	Nature/Position	Length	Width	W/L
Pachyportax nagrii	UOPC 21/02*	M2	22.3mm	17.2mm	0.77
	PUPC 13/307	IM1	23.95mm	21.60mm	0.9
	PUPC 13/287	lM2	22.95mm	21.65mm	0.92
	PUPC 15/393	lM2	22.40mm	21.00mm	1.11
	PUPC 13/306	IM2	22.65mm	24.80mm	0.86
	PUPC 13/373	IM3	22.80mm	20.35mm	0.94
	PUPC 14/20	IM2	21.66mm	21.45mm	1.15

Figure 5: (a) *Pachyportax nagrii*: 2021/02 An isolated right M2 Occlusal view.

Figure 5: (b) *Pachyportax nagrii*: 2021/02 an isolated right M2Lingual view.

Figure 5: (c) *Pachyportax nagrii*: 2021/02 an isolated right M2 labial view

Genus: Pachyportax Pilgrim, 1937

Species type: *Pachyportax latidens* Pilgrim, 1937

New material: UOPC 2021/03, m3 (Section-1)

Description and Comparison:

UOPC 2021/03 is a lower molar that is partially damaged. Goat folds are present, and d hypoconulid is present alongside the cavity of enamel. Both praehypocristid and posthypocristid are prominent. The ectostyle is present that is transversely extended, and a less prominent spur is also present. Entoconid and metaconid ribs are present in the upper molar area. The enamel is slightly rugose. After analyzing the morphological characteristics and close measurements comparison this specie belongs to *Pachyportax latidens*. As their size and shape differ it from *P. nagrii* (Figure 11 and 6 (a, b, and c).

Table 4: The comparative measurements of Pachyportax latidens. *The studied specimens. Referred data is taken from Mehmood et al., [66]

Taxa	Inventory Number	Nature/Position	Length	Width	W/L
Pachyportax latidens	UOPC 21/03*	M3	27.5mm	20.2mm	0.73
	PUPC 15/178	LP3	19.70mm	17.50mm	0.89
	PUPC 14/120	rP4	17.10mm	21.45mm	1.25
	PUPC 13/242	lM2	25.80mm	24.60mm	0.95
	PUPC 15/285	rM2	22.90mm	22.00mm	0.85
	PUPC 15/79	rM2	26.95mm	24.70mm	0.92
	PUPC 13/304	IM3	31.33mm	28.40mm	0.91

Figure 6: (a) *Pachyportax latidens*: 2021/03 lingual view an isolated partially broken right m3

Figure 6: (b) *Pachyportax latidens*: 2021/03 an isolated partially broken right m3 Labial view

Figure 6: (c) *Pachyportax latidens* 2021/03 an isolated partially broken right m3occlusal view

Genus: Kobus A. Smith, 1840

Species type: *Kobus porrecticornis*

New Material: UOPC 2021/04, P4 (Section-1)

Description and Comparison:

On the labial side, lobes are present constrictedly. Paracone is present on crown curvatures of teeth. Rounded cusps and deep fossetts are present in all teeth. Praeprotocrista is prominently present on lingual side. Anterior side is dominant with deep labio lingual lobes and median ribs. Ectostylids are present on the centre of labial side. Parastyle is well developed and evidently shown from the Occulusal view of fragment. The specimen posses high crown and shape is quadrate. The sample refer to *Kobus porrecticornis* on the basis of morphological features and differ from other species (Figure 11 and 7 (a, b, and c).

Table 5: The comparative measurements of Kobus porrecticornis. *The studied specimens. Referred data is taken from Iqbal, Khan and Akhter ***[67]***

Taxa	Inventory Number	Nature/Position	Length	Width	W/L
Kobus porrecticornis	UOPC 21/04*	P4	24.3mm	19.4mm	0.79
	PUPC 84/98	rp3	10.40mm	4.55mm	0.44
	PUPC 13/300	IP4	19.55mm	9.20mm	0.47
	PUPC 13/302	rM2	19.55mm	12.97mm	0.66
	PUPC 15/168	rM2	19.81mm	11.66mm	0.59
	PUPC 83/837	IM1	16.5mm	10.8mm	0.65
	PUPC 88/03	rm2	17.4mm	9.60mm	0.55

Figure 7: (a) *Kobus porrecticornis*: 2021/04 An isolated right p4 Occlusal view

Figure 7: (b) *Kobus porrecticornis*: 2021/04 an isolated right p4lingual view.

Figure 7: (c) *Kobus porrecticornis*: 2021/04 An isolated right p4 labial view

Genus: Kobus A. Smith, 1840

Species type: *Kobus porrecticornis*

New Material: UOPC 2021/05, P4 (Section-1)

Description and Comparison:

The specimen showed prominent conids and stylids as shown in figure11(5c). Hypsodont teeth are present from labial side view. Caprini folds are present in upper fourth premolar. Smooth enamel is appeared on premolars. The structure of antero-posterior fossettes is complicated and comprise of spurs/indentations. Overall structure and morphological features resemble with *Kobus porrecticornis* (Figure 11 and 8 (a, b, and c).

Table 6: Comparative measurements of Kobus porrecticornis. *The studied specimens. Referred data is taken from Saddiq et al., [68]

Taxa	Inventory Number	Nature/Position	Length	Width	W/L
	UOPC 21/05*	P4	24.3mm	19.4mm	0.79
	PUPC 84/98	rp3	10.40mm	4.55mm	0.44
Kobus porrecticornis	PUPC 13/300	IP4	19.55mm	9.20mm	0.47
	PUPC 13/302	rM2	19.55mm	12.97mm	0.66
	PUPC 15/168	rM2	19.81mm	11.66mm	0.59

	PUPC 83/837	IM1	16.5mm	10.8mm	0.65
	PUPC 88/03	rm2	17.4mm	9.60mm	0.55

Figure 8: (a) *Kobus porrecticornis*: 2021/05 Occlusal view. An isolated highly damaged upper pre molar

Figure 8: (b) *Kobus Porrecticornis*: 2021/05 An isolated highly damaged upper pre molar lingual view.

Figure 8: (c) *Kobus porrecticornis*: 2021/05 an isolated highly damaged upper pre molar labial view.

Genus: Kobus A. Smith, 1840
Species type: *Kobus porrecticornis*
New Material: UOPC 21/07, p4 (Section-1)
Description and Comparison:

This dentition is an isolated left deciduous fourth pre molar. This specimen is highly damaged. The stage of enamel is rough. Entostyle is present. Fossettes are absent. Constricted lobes are present and are hyposodont. Ectostylids, ribs and styles are damaged. All the morphological features can't be seen clearly due to highly damaged stage of dentition. Therefore, the overall morphology resembles it with *Kobus Porrecticornis* (Figure 11 and 9 (a, b, and c).

Table 8: The comparative measurements of Kobus Porrecticornis.*The studied specimens. Referred data is taken from Saddiq et al., [68]

Taxa	Inventory Number	Nature/Position	Length	Width	W/L
Kobus porrecticornis	UOPC 21/07*	P4	24.3mm	19.4mm	0.79
	PUPC 84/98	rp3	10.40mm	4.55mm	0.44
	PUPC 13/300	lP4	19.55mm	9.20mm	0.47
	PUPC 13/302	rM2	19.55mm	12.97mm	0.66
	PUPC 15/168	rM2	19.81mm	11.66mm	0.59

	PUPC 83/837	IM1	16.5mm	10.8mm	0.65
	PUPC 88/03	rm2	17.4mm	9.60mm	0.55

Figure 9: (a) *Kobus porrecticornis*: 2021/07 an isolated left deciduous p4 occlusal view.

Figure 9: (b) *Kobus porrecticornis*: 2021/07 an isolated left deciduous p4 lingual view.

Figure 9: (c) *Kobus porrecticornis*: 2021/07 An isolated left deciduous p4 labial view. Genus: Pachyportax Pilgrim, 1937

Species type: *Pachyportax latidens*
New Material: UOPC 21/06, m2 (Section-1)
Description and Comparison:

UOPC 21/06 is an isolated left lower molar (M2) with prominent cusps. Ectostylid projection is more dominant on the labial side. Post-protocrista is more evident on the anterior side of fragment. The dentition is narrow crowned. Long and well preserved talonid are present. Between the hypoconid and protoconid, median basal pillars are present. Narrow central cavity is present. Both meta-stylid and mesostylid are present. Towards the anterior ridge, wear is more confined than the posterior one. Both the posterior and anterior median rib is present. All the morphological characteristics of the sample resembles with *Pachyportax latidens*. Furthermore, comparative measurements also refer to this specie to *Pachyportax latidens* on the basis of size and shape and differs it from the other species. So, it is attributed to *Pachyportax latidens* (Figure 11 and 10 (a, b, and c).

Table 7: The comparative measurements of Pachyportax latidens. *The studied specimens. Referred data is taken from Mehmood et al., [66]

Taxa	Inventory Number	Nature/Position	Length	Width	W/L
Pachyportax latidens	UOPC 21/06*	M2	25.3mm	20.60mm	0.81
	PUPC 15/178	IP3	19.70mm	17.50mm	0.89
	PUPC 13/242	IM2	25.80mm	24.60mm	0.95
	PUPC 15/79	rM2	26.95mm	24.70mm	0.92

PUPC 13/304	rM3	31.33mm	28.40mm	0.91
PUPC 13/68	IM3	34.55mm	31.10mm	0.9
PUPC 85/29	rp4	23.3mm	13.33mm	0.57

Figure 10: (a) *Pachyportax latidens*: 2021/06 An isolated left m2 lingual view.

Figure 10: (b) *Pachyportax latidens*: 2021/06 An isolated left m2 labial view.

Figure 10: (c) *Pachyportax latidens*: 2021/06 An isolated left m2 occlusal view.

Discussion:

Our planet's geological history conceals an enigmatic past, while newly discovered Bovid fossils provide a scientific basis for exploring a lost world. Although the Indian plate may now appear isolated, confined by the Himalayas to the north, the Suleiman Fold and Thrust Belt in the western part (uplifted due to its collision with the Afghan Block), and the Indian Ocean to the south, it hasn't always been inaccessible for extended periods to migrating mammals [13]. The constantly shifting tectonic, morphological and climatic conditions within the Indian plate have led to ongoing changes in the composition of its fauna. This has led to the movement of species, their disappearance, and the development of unique endemic forms, with the subsiding foreland basins along the Himalayan foothills being essential for preserving a rich history of sediments and associated fauna.

The Siwaliks, known for its rich vertebrate fossil record in Potwar, Pakistan [21], have unearthed new findings that explained the dynamics of artiodactyl fauna around ~7-5.5 Ma. Particularly, in the examined Dhok Pathan Formation in its type locality and Hasnot village, we find a compelling link between tectonic activities and the distribution of Miocene fauna. The Siwaliks provides an excellent opportunity to study the ultimate closure of the Tethys and replacement of seaway during the Late-Oligocene to Early-Miocene [69]. This seaway was replaced by a fluvial system that laid the foundation for the contemporary drainage pattern in the present-day Pakistan. The Late-Miocene and Early-Pleistocene, marked by colder more arid climatic conditions, the expansion of grasslands, and sea level changes, likely impacted the interchange of bovids [13]. *Artiodactyls* were present in Eurasia, India, and North America during the Early Eocene, around 55 million years ago [70]. The "hard" collision between the Indian plate and Asia, which shaped the oriental biogeographic province, likely occurred between 25 and 20 million years ago, allowing early artiodactyls and perissodactyls to disperse within this region until the Early Miocene. The investigation of numerous carbon isotopes ratio of soil carbonates from paleosols in various Siwalik units of Pakistan, Nepal, and India has revealed a change from clean C_3 to hybrid C_3-C_4 vegetation's in the Late Miocene [71]. The date of the C_3 to C_3-C_4 hynrid transition varies in various Siwalik locations, such as, it was approximately 7.7 million years when their growth in C_4 plants began quickly in Pakistan's Siwaliks. For example, C_4 plant diversification began fast in the Pakistani Siwaliks around 7.7 Ma [72], while these incidents occurred after 0.7 million years in the area of Surai-Khola region of Nepal Siwalik [73], or the C_4 plant diversification began at 6 Ma in the Kangravalley, India [74]. In the Indian Subcontinent floodplain C_4 plants are highly present [71], but C_3 woods were found at higher elevations and along the frontal Himalayan foothills. It is thought that there existed an equilibrium in the carbon cement deposition in sandstone nodules and CO_2 in shallow ground water, and that some of these were replenished by C_3 plants located beneath it in the surrounding upland areas [75]. As a result, if C_4 plants dominated the local soil cover, the ^{13}C of soil carbonate and carbonate cement of sandstone nodule from nearby beds may differ [74].

Several bovid taxa, including *Tragoportax, Pachyportax, Gazella*, and *Selenoportax*, are found in South Asia, with their same presence in the Dhok Pathan Formation. These genera exhibit dominance not only in the Siwalik region but also in Eurasian deposits [76, 77]. Hasnot Village is notable for its abundance of vertebrate fossils, which encompass the orders *Artiodactyla, Perissodactyla, Proboscidea,* and *Primates,* are prevalent in Hasnot Village [61, 78, 79]. Particularly, among these fossils, bovids of the Artiodactyla order are more prevalent in comparison to other taxa Siwalik artiodactyls are predominantly represented by cranial and postcranial remains, with notable connections to artiodactyls from both Africa and Eurasia[80]. Large-bodied animals such as *Pachyportax* and *Selenoportax* existed throughout the Late Miocene and disappeared before the end of the Pliocene. *P. latidens* and *P. nagrii* are two dominated, small sized species of pachyportax [81, 82]. *Selenoportax* also represented by *S. vexillarius* specie. The *Kobus porrecticornis* has been exposed from the Late-Miocene to Pliocene of Dhok Pathan Formation (ca. 7.4-2.9 Ma).

Evolution of Bovidae in Pakistani Siwaliks:

The bovids of early Miocene, which were relatively small and had simple dental and cranial structures [83], are not reported in detail, making it difficult to understand their early evolution and distribution in Pakistan [6]. While, in the Siwaliks subgroup, Bovid consists of a wide group of species. *(Selenoportax vexillarius, S. lydekkeri, Pachyportaxlatidens, P.nagrii, Tragoportax salmontanus, T.punjabicus, T. indet., Miotragocerus sp., cf. Sivaceros, Eotragus sp., Elachistocera skhauristanensis)* of Boselaphines are the 11 species of Boselaphines that are present between 3.5 and 11 Ma. Moreover, there are two *reducines* and 1 or 2 antilopes. The first bovid records at the Early Miocene of Vihowa Formation (pre-Siwalik rocks in Pakistan) about 19 Ma [84]. However, *Eotragus* reports from the Kamlial Formation of the Siwaliks in the Potwar Plateau at about 17.8 Ma [85].

The taxonomy of bovid located in the Middle Miocene of Siwalik Subgroup spots completely hidden from the Potwar Plateau of Siwalik recorded by 12.5 million years ago, at which point *Selenoportax vexillarius, Pachyportax latidens, Elachistoceras khauristanensis,* and a small *Gazella* become very peculiar. Species turnover occurs in *Selenoportax* and *Pachyportax* during the Late Miocene, and new species emerge, which include *reducines* and antilopines [86]. Geographically, two bovid's *pachyportax* and *selenoportax* limited to the Siwalik group, have been abundantly discovered in Late Miocene-Early Pliocene Siwalik localities. At the late Miocene siwalik spots, *Reducines* are uncommon with only one or two species present. During the late Miocne to Early Pilocene, Alcelaphin bovids were not found in the Siwaliks.

The Siwaliks' Late Miocene-Early Pliocene bovids show a tendency to grow in size [87]. In the Siwaliks, the dominant groups were Boselaphini and *Antilopini* [88]. The tribe Boselaphini's Middle Miocene Siwalik record yields two lineages that lead to *Sivaceros*-

Miotragocerus and *Strepsiportax-Tragoportax-Selenoportax*. Gazella *lydekkeri* is a new antilopine that shares the Late Miocene stage with the boselaphines [88].

Bovids as paleo-environment indicators

The appearance of very long legs with significantly longer metapodials suggests that *Selenoportax* and *Pachyportax* adapted to the more open habitats, such as the living bovids [89]. Hypsodont teeth are mostly present in *tragoportax*. About 3.3 million years ago, in the tatrot formation, the same high crowned species are present suggested to open habitats. *Eotragus* appears to have been a browser, that mostly used to live in various environments/habitats such as woodlands to grasslands, distinguished from low seasonal climates to swamp's deposits [90]. When we compare *rednucines* with their other living relatives present in Arabian Peninsula or Africa, they might lived-in water-logged habitats and sustaining subsurface wetlands. In the Siwaliks Subgroup, *Kobus Porrecticornis* lived in the same habitats might be assumed [67].

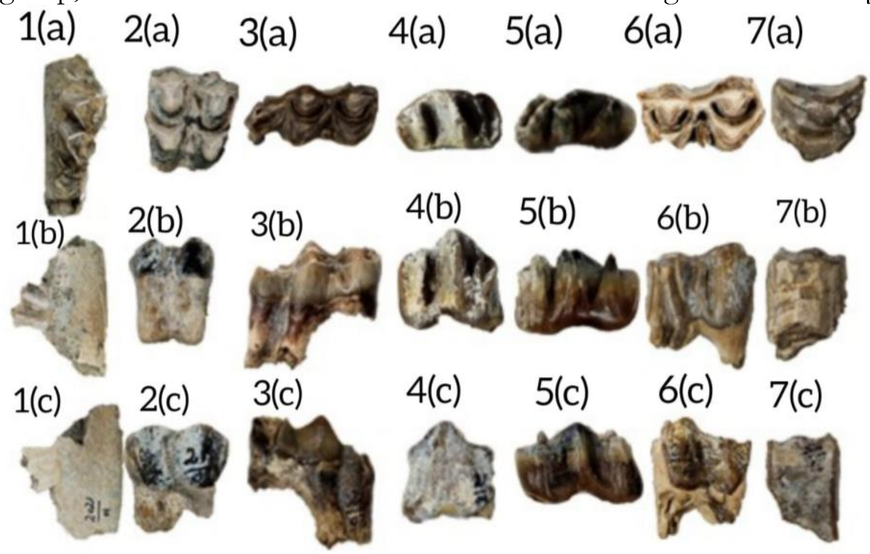

Figure 11: Representative mandible of *Selenoportax vexillarius*: 1. UOPC 2021/01, m3. *Pachyportax nagrii:* 2. UOPC 2021/02, M2. *Pachyportax latidens:* 3. UOPC 2021/03, m3. *Kobus Porrecticornis:* 4. UOPC 2021/04, p4. 5. UOPC 2021/05, P4. *Pachyportax latidens:* 6. UOPC 2021/06, m2. *Kobus Porrecticornis:* 7. UOPC 2021/07, p4. Scale bar is equal to 10mm. a= occulusal view, b= lingual view and c= labial view

The primitive cervines are most likely distributed tropically, and were lived in forests and open region rather than close woodlands [91]. After 7.4 Ma, carbon isotopes also indicates the presence of open woodlands or grassy woodlands [6]. The Siwalik's cervid is mostly found in open woodland habitats [79, 91]. Although the premolars have been molarized, *Bramatherium* keeps low crowned xxii cheek teeth, which are typical of browsers [92]. *Dorcabune, Eotragus, Elachistoceros, Tragoportax, Miotragocerus, Selenoportax* and *Pachyportax* are example of the typical browsing community represents *Dorcatherium majus* and *D.minus* [93]. *Dorcatherium* prefers closed low canopy forest with minimal ground cover due to its small territory [94]. Plenty of tiny open standing water bodies such as ponds and too much moist environment indicating the occurrence of *Tragulids* [95]. Densely forested areas, the humid and the warm climate with less seasonality are the indicators of nearby presence of *Tragulids.*

Gazella is also termed as a mixed feeder [96]. Very balanced mix feedings are usually resembled with *Gazella's* dental micro wear [97]. Moreover more open habitats and browser feeding has been suggested for *Gazella* [98]. Ecological differences clearly represented the absence of alcelaphines.

Announcing the mixture of habitats, in the Siwalik Late Miocene to Early Pliocene, The bovids are typically common component overall [99]. Larger taxa, such as *Dorcatherium*, are likely to be dependent on grasses, which are linked to damp pastures, deltas, or perpetual drainages [100]. *Suids* and *Giraffids* are both found in open woodlands and are thought to eat various food items. Thereby further, the Siwalik Late Miocene artiodactyls may have had access to a variety of habitats, including the areas near water, bush, swamp, woodland, savannah and light bush and they all represents the wide variety of habitats of Siwalik Late Miocene [85].

The region had an arid paleoclimate during the Late Miocene, featuring isolated forested areas. Changing to a drier and seasonal climate may have led to artiodactyl extinctions. The artiodactyls of our studied area preferred open and drier woodland mosaics, with medium-sized species indicating the presence of wooded-grassy savannas and grasslands.

Conclusion

From outcropped lithologies of Dhok Pathan Formation (Upper Siwaliks age ~7.0-5.0 Ma) at Dhok Pathan and Hasnot villages of Punjab, Pakistan, subgroup, *Selenoportax vexillarius*, *Pachyportax latidens*, *Pachyportax nagrii* and *Kobus porrecticornis* were recovered (Figure 11). The dental remains of *Selenoportax* from Siwaliks in Punjab, Pakistan date back to the late Miocene share similarities to those from Central and Northern Asia. This research completely evidences the variety of faunal elements of Bovids in the Siwaliks Pakistan and raises more questions for further study.

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